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SYNOPSIS The following case history presents innovative geotechnical solutions which allowed the simultaneous construction of two overlapping projects, by two different contractors, sponsored by different governmental agencies under tight project schedules. A settlement sensitive Light Rail Transit (LRT) line was to cohabitate the same alignment as a new freeway with embankment heights of 27 feet; both of which are on compressible and weak subgrade soils. Construction activities could not impinge on one or anothers project. The geotechnical concepts used allowed the two projects to proceed simultaneously and minimized the impacts of embankment induced settlement on the two LRT tracks. Field monitoring confirmed the expected soil movements were not greater than the tolerable limits for either project.

INTRODUCTION

In San Jose, California the design of a combined Light Rail Transit (LRT) and Route 85 freeway transportation system required the 50 foot wide LRT system to be installed within the proposed freeway median. At one point, the LRT alignment diverges from the freeway alignment and heads in another direction. To allow the LRT to diverge from the freeway alignment, the freeway grade was raised as much as 27 feet to pass over the LRT (Figure 1). Vertical bridge abutment fill slopes, retained by walls, were used to minimize the needed length of freeway bridge. This created an at-grade tunnel-like bridge structure. Innovative geotechnical engineering was needed to allow simultaneous construction of both facilities and to eliminate the consequences of settlement on the bridge approach slab and the LRT tracks. Within the bridge area, where embankment heights reached 27 feet (37 feet considering surcharge fills)

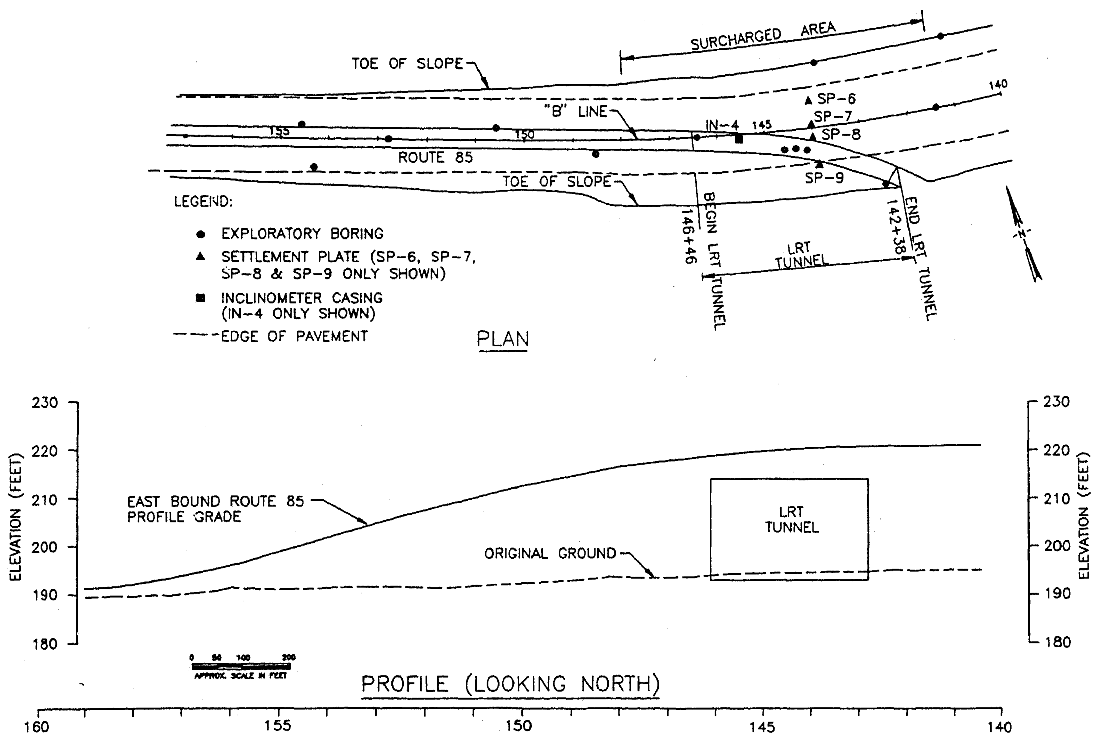

Figure 1. Project Plan and Profile

the basal stability was marginal considering the measured strengths of the subgrade soils. Soldier beams, used as part of the embankment shoring system, were also used to penetrate the weak soils and to increase the overall basal stability.

Vertical slopes were also necessary on the sides of the freeway embankment as it approached the tunnel-like bridge structure. Conventional retaining walls were not practical due to the need to keep the adjacent LRT right-of-way unencumbered.

SITE CONDITIONS

The project site includes mostly a relatively flat orchard area, with ground surface ranging between Elevation 192 and 195.

Based on the logs of seven borings and two groundwater observation wells taken during our investigation of September 1988, the generalized soil profile is described as follows:

Depth (feet)	Soil Description
0 to 5	Silty Clay (CL), very stiff to hard
5 to 24	Silty Clay (CL), soft to stiff
24 to 27	Silty Sand (SM), medium dense
27 to 45	Silty Clay (CL), soft to stiff
45 to 100	Sandy Gravel and Gravelly Sand (GW to SW), dense to very dense, interbedded with lenses of silty clay from 60 to 75 feet

This generalized profile along "B" Line is shown in Figure 2.

In summary, thick layers of compressible clayey soils were generally encountered between depths of about five to 45 feet below ground surface. Underlying the clay deposits are incompressible granular deposits extending from a depth of about 45 feet to beyond the terminal boring depths of 100 feet.

Groundwater measurements taken in the area indicate it was at a depth of about 68½ feet at the time of this study. Historical data indicates that groundwater levels were encountered at about 20 to 30 feet. This drop in groundwater level could be due to the groundwater "pump and treat" process that has taken place in a nearby computer manufacturing facility.

The upper clay units were partially saturated. From depths of 3 to 38 feet, the soils vary from about 70 percent to 100 percent saturation. The degree of saturation increases with depth. To estimate the consolidation characteristics of the clay soils, six consolidation tests were performed on saturated samples.

Menard pressuremeter tests were used to estimate the in-situ properties of the soil, in particular the stress-strain behavior of clay layers. Based on the pressuremeter tests the overconsolidation ratios (OCR) of the clay stratum were estimated to vary between 1.6 to 3.5. By comparison, laboratory consolidation tests indicated the OCRs range from 1.0 to 2.5.

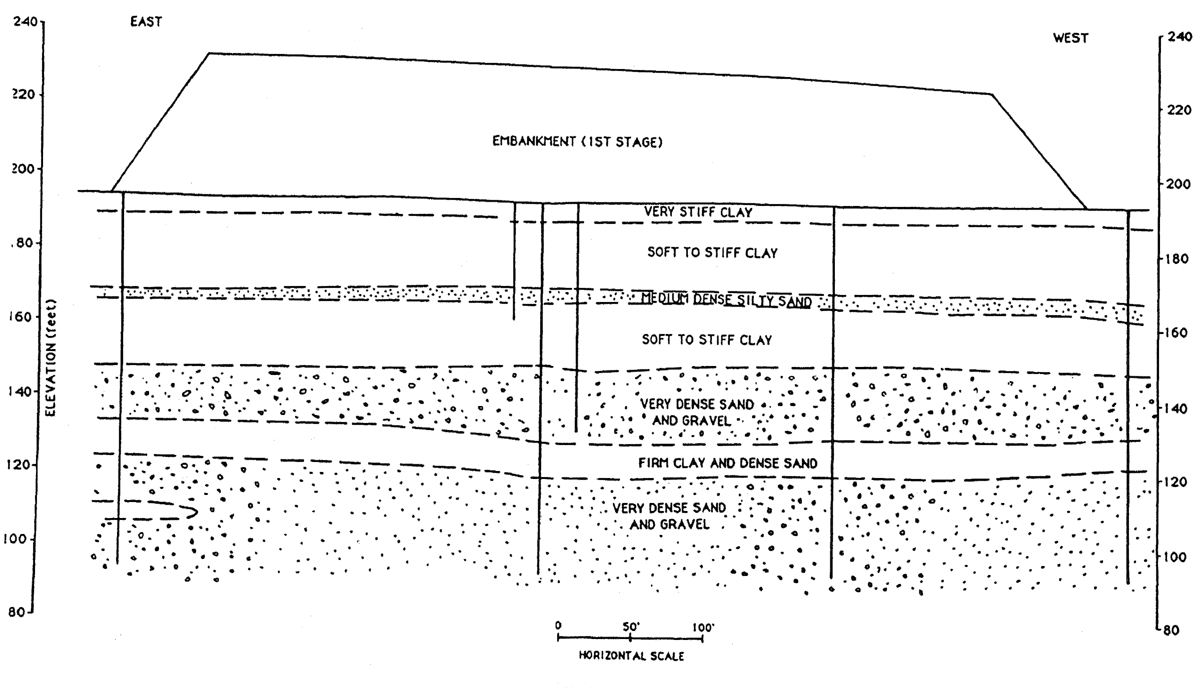

Figure 2. Generalized Soil Profile along "B" Line, Looking South

GEOTECHNICAL CONCEPTS

As shown in Figure 1, the new highway embankment between Stations 157+00 and 140+00 will range in fill heights from 4 to 27 feet. The project included (see Figure 1) construction of the LRT tunnel between Stations 146+46 to 142+38, a short length of retaining walls east of the east end of the tunnel, and a pair of retaining walls down the middle of the freeway between Stations 146+46 to 156+50. The LRT tracks are relatively level and follow the original ground surface. As shown in Figure 3, the 400 foot long LRT tunnel has a rectangular cross section with dimensions of approximately 40 feet (wide) and a vertical clearance of about 19 feet. It consists of a rigid reinforced concrete frame supported on vertical end-bearing piles, with a system of horizontal struts connecting the pile caps. A 50 foot wide right-of-way was required for the LRT system.

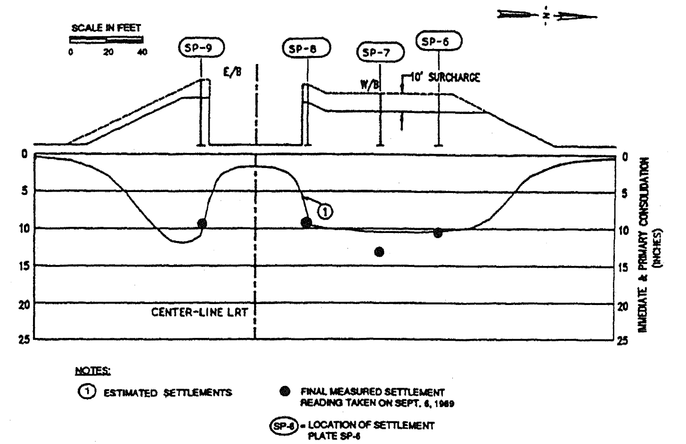

Figure 4. Estimated and Measured Settlement at Station 144+00

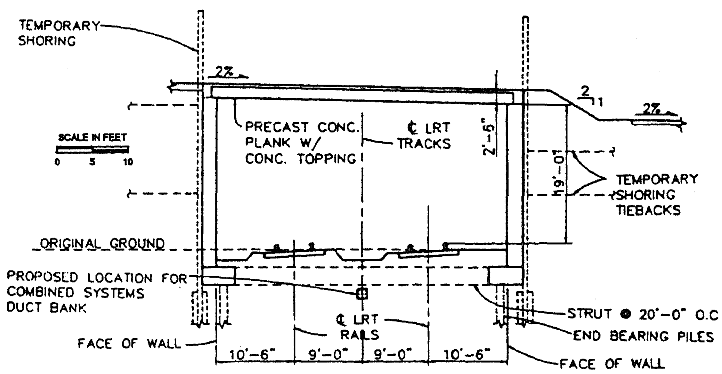

Figure 3. Typical Section at LRT Undercrossing

Construction of the Route 85 embankment fill was estimated to cause significant settlements throughout the area since the soils at the site include compressible materials. Settlements were estimated at several locations throughout the entire project area. Estimated immediate plus primary consolidation settlements (with no surcharge) at Station 144+00 are presented in Figure 4. Furthermore, estimated settlements were also made for a 10 foot surcharge. The maximum embankment settlement estimated for no surcharge was about 18 inches, whereas a maximum settlement of about four inches was estimated within the LRT alignment. Differential settlement along the track could be as much as three inches in 200 feet. Based on this analysis, it was concluded that the track system, if installed before or concurrently with the freeway approach embankments, would undergo excessive settlement.

Construction schedules limited the potential surcharge time to only 90 to 120 days; furthermore, surcharging was restricted to the area between approximately Stations 142+00 and 147+50 in order to allow simultaneous construction of the LRT. The estimated time rate of settlements considered the partially saturated in-situ condition of the soils. Based on the results of the consolidation tests, as well as experience on nearby projects, it was estimated that a 10 foot high surcharge would preconsolidate this area in the available 90 to 120 day time, causing settlements equal to those that would occur due to the embankment alone at the end of primary consolidation. Rail placement was delayed until the end of the 90 day settlement period.

The 10 foot high surcharge resulted in temporary embankment fills as high as 37 feet. Since the LRT construction contract required the 50 foot wide LRT center portion to remain open during construction, a temporary flexible wooden lagging and steel soldier pile shoring system with a maximum height of 37 feet was used to retain the embankment and surcharge fill. The soldier piles for the shoring system extended to depths of 30 feet which bypassed the soft clays and embedded into medium dense deeper granular soils to increase slope stability and develop sufficient lateral resistance. The flexible shoring wall had the advantage of being able to deform as the embankment settled. The shoring wall was restrained by two levels of anchors (steel bars) connected each to a cast-in-place concrete deadman placed in the embankment fill. A photograph of the completed shoring system is shown in Figure 5. The exposed shoring face system subsequently served as the back form for the bridge abutment walls of the LRT tunnel.

West of the LRT tunnel, the embankments along both sides of the LRT right-of-way between approximately Stations 146+46 and 156+50 (see Figure 1) were retained by means of a soil reinforcement system. A "Mechanically Stabilized Embankment" (MSE) system was one of those considered; it utilizes welded wire mat reinforcements and precast concrete panels. Based on settlement analysis, it was estimated that the embankment walls could probably experience maximum differential settlements of about five inches over a distance of 100 feet. Since this settlement was

Figure 5. Photograph of LRT Tunnel and Embankment during Construction

considered to be less than the tolerable differential wall settlement, surcharging/preconsolidation was not considered necessary in this area.

The LRT tunnel structure is supported on 70 ton capacity vertical piles. These piles were driven to end bearing in the dense sand and gravel encountered at a depth of about 45 feet below original ground surface.

After stripping of topsoil was accomplished, a 12-inch thick drainage blanket of permeable material was placed on the ground surface in the area of the proposed embankment fills. The primary purpose of this drainage blanket was to intercept water, in the event that some of the pore water in the upper clay layers drained freely to the ground surface when squeezed out of the soil mass due to consolidation. Imported embankment fill was then placed in thin lifts, moisturized as needed, and compacted. Wood lagging was installed simultaneously as fill was placed.

Maximum fill and shoring height was about 37 feet, including 10 feet of temporary surcharge. Filling operation was completed on June 28, 1989. The estimated midpoint of filling operation was about June 4, 1989. Based on the necessary surcharge fill removal date of September 18, 1989, the effective consolidation period was about 107 days. All surcharge was removed by October 16, 1989.

CONSTRUCTION MONITORING

Settlement Plates

A total of 16 settlement plates were installed, and four locations (SP-6, SP-7, SP-8 and SP-9) are shown in Figure 1. Initial settlement plates (SP-1, SP-2, SP-6 and SP-7) were installed on March 9, 1989. Subsequent settlement plates were installed during initial filling of embankment on the following dates:

- SP-10, SP-11, SP-13 and SP-14 on May 5, 1989
- SP-3 and SP-8 on May 13, 1989
- SP-4, SP-9, SP-12 SP-15 and SP-16 on May 18, 1989
- SP-5 on June 28, 1989

Placement of essentially the remainder of the settlement plates was completed by May 18, 1989, followed by more fill placement.

These settlement plate locations correspond to profiles at these four approximate station locations: Stations 143+00, 144+00, 145+00 and 147+00. The plates consist of 12 inch square steel plates placed on the level surface of the permeable material. Five (5) foot long sections of galvanized iron pipe and PVC casing were attached to each plate, and then subsequently to one another, as fill was being placed. Settlement of each plate was periodically measured during and after fill placement. The approximate height of fill at each settlement plate location was also measured during the field survey.

Settlement Versus Time

A graph of settlement versus time and fill height versus time for each settlement plate was prepared; one typical graph for SP-7 is shown in Figure 6. This figure shows the elapsed time in days and when fill placement was completed, including the 10 feet of surcharge. The last set of settlement plate readings were taken on September 6, 1989.

Since filling was completed on June 28, 1989, the fill with full surcharge was in place for a period of 70 days when the final settlement readings were taken on September 6, 1989. The actual time, counting between the time when one-half of the embankment and surcharge was constructed on about June 4, 1989, until September 6, 1989, was 94 days.

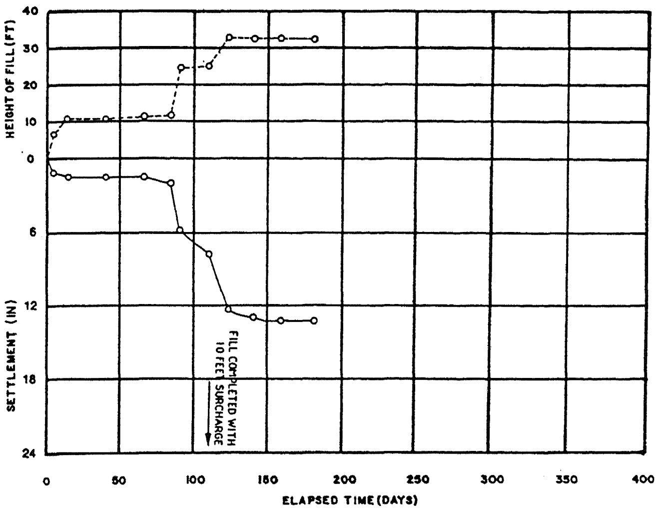

Figure 6. Measured Settlement versus Time for Settlement Plate SP-7

Based on the monitored data plotted in Figure 6 and at remaining settlement plates, the following conclusions are made:

- Fill was placed in 1, 2, or 3 stages, depending upon where and when deadmen were installed.
- Settlement occurred almost as rapidly as fill was placed and then rates slowed considerably afterwards.
- Settlement essentially ceased in a period of 70 days, counting from the time when one-half of the embankment fill was in place; this time period was consistent with the predictions.
- As of the last set of readings taken on September 6, 1989, essentially all of the immediate and primary consolidation settlement with respect to the design height embankment has occurred.

Comparison of Measured Settlements with Estimated Settlements

The estimated settlements throughout the entire area were presented previously in the section entitled "Geotechnical Concepts". The estimated settlements (without surcharge) for Station 144+00 are shown in Profile 1 in Figure 4.

The final measured settlement was taken on September 6, 1989 at each of the 16 settlement plates. As shown on Figure 4, the last measured settlement at Station 144+00 for settlement plates SP-6, SP-7, SP-8 and SP-9 falls close to the estimated settlement. In most of the other cases, the measured settlement is also close to the estimated settlement. Maximum measured settlement at Station 144+00 was about 14 inches.

Vertical Inclinometer Monitoring

A total of four vertical inclinometers (IN-1, IN-2, IN-3 and IN-4) were installed within the LRT right-of-way; the location of IN-4 is shown in Figure 1. Inclinometers were installed on May 5 (IN-4), May 23 (IN-2), May 24 (IN-3) and May 25, 1989 (IN-1). Each inclinometer casing extended to a depth of about 60 feet below existing ground surface. Baseline readings were taken between May 15 and May 30, 1989. Approximately 12 to 14 feet of embankment fill was in place when the baseline readings were taken; baseline readings could not be taken earlier since ongoing construction limited drill rig access to install the inclinometers. Periodic readings (typically on a weekly basis) were subsequently taken until the final set of readings was obtained on September 12, 1989. The profile of lateral soil movement in inclinometer IN-4 at Station 145+50, as measured on July 31 and September 12, is shown on Figure 7. These measurements were taken in a plane perpendicular to the shoring walls along the LRT right-of-way. The maximum movement observed, as of September 12, 1989, was about 0.35 inch in all four inclinometers, and about 0.30 inch at IN-4. In the six week period between July 31 and September 12, the incremental movement was relatively small, less than 0.10 inch. This indicates lateral ground movement had practically ceased by September 12, 1989, in the vicinity of the shoring caissons. This further substantiates the stability of the shoring system.

Most caissons extended to depths of about 30 feet. Detectable lateral ground movement was measured below this depth in only IN-1 and IN-4 (Figure 7), where

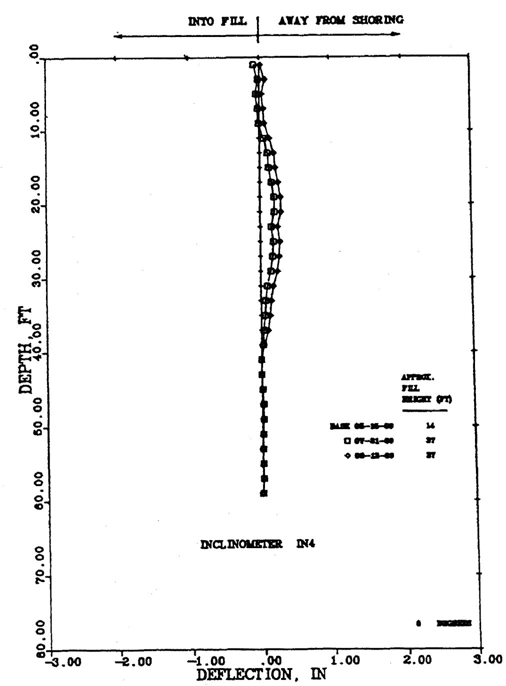

Figure 7. Measured Soil Deflection at Inclinometer IN-4

deflections of order 0.30 inch and 0.20 inch were noted. Below depths of 45 feet and 40 feet at these two locations, however, there was no perceptible movement.

An earthquake on August 8, 1989, resulted in no apparent increase of soil lateral movement at the four inclinometers.

CONCLUSIONS

Settlement

Based on the results of the settlement monitoring program, the following conclusions are reached:

- Maximum measured settlement was about 14 inches. The measured settlement compares favorably with the estimated magnitude of settlement.
- The measured settlement rate compares favorably with the estimated settlement rate.
- Elastic and primary consolidation settlement was essentially complete when the last set of settlement plate readings was taken on September 6, 1989.
- The objective of the advanced embankment surcharge program was met.

Inclinometers

Based on the results of the inclinometer monitoring program, the following conclusions are reached:

- Maximum lateral ground movement, and hence lateral caisson movement, was about 0.35 inch.
- The 30 foot deep caissons, designed to increase the overall slope stability of the foundation soil, performed as anticipated and the shoring system proved stable.
- The small increase in lateral soil movement over the last six week construction period ending on September 12, 1989 indicates lateral movement had essentially ceased.

SUMMARY

The unconventional use of soldier beam and lagging allowed the simultaneous construction of two conflicting projects of two conflicting agencies. Measured settlements and horizontal movements confirmed that the predicted deformation had been essentially complete within the predicted time frame.

Based upon these results, as well as engineering judgment, the objective of the advanced embankment surcharge was met. From a geotechnical standpoint, it was felt that construction could proceed and that no further monitoring was required. Based on these results, the second construction contract proceeded on schedule. This freeway was opened to traffic in the spring of 1992.

ACKNOWLEDGEMENT

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